

Does Amati Relation Depend on Luminosity of GRB's Host Galaxies?

Jing Wang, Jing-song Deng and Yu-lei Qiu¹

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China

Abstract In order to test systematic of the Amati relation, the 24 long-duration GRBs with firmly determined $E_{\gamma, \text{iso}}$ and E_p are separated into two sub-groups according to B-band luminosity of their host galaxies. The Amati relations in the two subgroups are found to be in agreement with each other within uncertainties. Taking into account of the well established luminosity - metallicity relation of galaxies, no strong evolution of the Amati relation with GRB's environment metallicity is implied in this study.

Key words: gamma-rays: bursts - gamma-rays: observations - galaxies: evolution

1 INTRODUCTION

Several relations between observable properties have been found for Gamma Ray Bursts (GRBs) observed in past few years (see Schaefer 2007 for a review). Among these relations, an important one is the Amati relation that is a correlation between the total isotropic-equivalent radiated energy in γ -ray ($E_{\gamma, \text{iso}}$) of long-duration GRBs (LGRBs) and their peak energy (E_p) of integrated νF_ν spectrum in the rest frame (Amati et al. 2002). This correlation is further confirmed and extended by subsequent observations (e.g., Amati 2003, 2006a,b; Sakamoto et al. 2004; Lamb et al. 2004). A similar relation between L_{iso} and E_p is found to be not only hold among different LGRBs but also hold among individual pulses of single LGRB (Liang et al. 2004). Although the correlation is highly significant, the dispersion of the correlation is expected to be not only caused by statistic fluctuation (e.g., Amati 2006a).

At present, LGRBs are generally believed to originate from the death of young massive stars (e.g., see Woosley & Bloom (2006) for a recent review). The popular collapsar model favors progenitors with low metallicity to preserve angular momentum when the collapse occurs (e.g., Woosley 1993; MacFadyen & Woosley 1999). A low metallicity environment has been indeed reported by the studies of host galaxies of both nearby and cosmologically distant LGRBs (e.g., Sollerman et al. 2005; Stanek et al. 2006; Fynbo et al. 2006). Because metal abundance plays an important role in the collapsar model, the evolution of the statistical properties of LGRB is therefore expected.

Li (2007) recently examined the cosmological evolution of the Amati relation by dividing 48 LGRBs with reported E_{iso} and E_p into four redshift bins. The Amati relation is found to vary with redshift with only $\sim 4\%$ of chance that the variation is caused by selection effect. Although it is generally believed that metallicity statistically evolves strongly with redshift, a number of extremely metal-poor galaxies, have been identified in the local Universe (e.g., Kewley et al., 2007; Izotov et al., 2006 and references therein). Since the metallicity is hard to be determined for a large sample of LGRBs at current, the luminosity (or stellar mass) of host galaxy could be used as a physically meaningful indicator of metallicity taking into account of the well established luminosity (or mass)-metallicity relationship ($L - Z$ relation, e.g., Tremonti et al., 2004; Savaglio et al. 2005). In this paper, we examine the variation of the Amati relation on luminosity of LGRB's host galaxy.

* E-mail: wj@bao.ac.cn

2 VARIATION OF AMATI RELATION ON LUMINOSITY OF HOST GALAXY

We compile a sample of LGRBs to examine whether the Amati relation varies with luminosity of host galaxy. The B-band luminosities of host galaxies are adopted from published literature, and is transformed to absolute B-band magnitude by adopting $M_B^* = -21$ mag. In order to avoid the selection effect, only the LGRBs with $0.2 < z < 2$ are considered, which leads the four nearby bursts, i.e., GRB 980425, GRB 030329, GRB 031203 and GRB 060218, are excluded from our sample. GRB 980425 is a sub-energetic LGRB and dose not found to satisfy the Amati relation. GRB 031203 has poorly determined E_p . The sample finally contains 24 LGRBs listed in Amati (2006). Table 1 lists the properties for each LGRB, including the redshift, rest-frame isotropic energy $E_{\gamma, \text{iso}}$ defined in 1-1000keV band, peak energy E_p in rest-frame, and k -corrected absolute B-band magnitude M_B of its host galaxy. The Λ CDM cosmology with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $h_0 = 0.7$ is adopted throughout the paper.

The redshift is plotted against M_B for our sample in Figure 1 (left-bottom panel). The diagram indicates that there is no clear trend of M_B on redshift in the range from $z = 0.2$ to $z = 2$. The Figure 1 upper panel shows the distribution of M_B of the 24 LGRBs. The M_B spans a range of -16 - -22 mag. In order to examine variation of the Amati relation on luminosity of LGRB's host, we separate the sample into two subgroups with identical contents, i.e., Group L and H, according to the luminosity of LGRB's host galaxy. The LGRBs with $M_B > -19.7$ belong to Group L, and these with $M_B \leq -19.7$ Group H (see vertical dashed line in Figure 1). Finally, each group contains 12 LGRBs. The bottom-right panel of Figure 1 shows the distributions of redshift for both subgroups (solid line for Group H and dashed line for Group L). In both subgroups, a majority of LGRBs are distributed in a narrow range from $z = 0.5$ to 1. A logrank test indicates that the redshift distributions of the two subgroups are drawn from the same parent population at a probability $\sim 70\%$.

Using 41 LGRBs with firmly determined $E_{\gamma, \text{iso}}$ and E_p , Amati (2006) obtained an updated relationship

$$\log E_{\gamma, \text{iso}} = a + b \log E_p \quad (1)$$

where $a = -3.35$ and $b = 1.75$ using the least squares fitting method; and $a = -4.04$ and $b = 2.04$ using the maximum likelihood method. A least squares fit to our 24 LGRBs as a single sample with Eq. (1) leads to $a = -3.25 \pm 0.40$ and $b = 1.69 \pm 0.16$ with $\chi_r^2 = 1.60$. The χ_r^2 is the reduced χ^2 , which is defined as the χ^2 of fit divided by the degree of freedom. The fitting is shown in Panel A in Figure 2. The two dashed lines in the Panel A mark the 1σ deviation of the best fit. This result is in good agreement with that obtained by Amati (2006) and Li (2007), which indicates that no additional bias is obviously introduced in the sample used in this paper by our sample selection.

Least squares fittings are also carried out for both Group H and L. The fittings are shown in Panel B and C in Figure 2 for Group H and L, respectively. In Group H, the best-fit Amati relation has parameters $a = -2.97 \pm 0.73$ and $b = 1.61 \pm 0.30$ (with $\chi_r^2 = 1.96$), which is similar to $a = -3.47 \pm 0.44$ and $b = 1.74 \pm 0.17$ (with $\chi_r^2 = 0.94$) obtained in Group L within uncertainties. In addition to the best fit of the Amati relation, the dispersion around the best fit also provides important information. Although the dispersion of Group H is slightly larger than that of the whole sample, the dispersion of Group L is found to be significantly suppressed (see also the χ_r^2 for each group). Figure 3 plots the distributions of deviation from the best fit in $\log E_{\gamma, \text{iso}}$. The distribution for the whole sample, Group H and Group L is shown in Panel A, B and C, respectively. As shown in the Panel C, the distribution of Group L is quite uniform with an obvious cut-off at ~ 0.6 . In contrast, Group H shows a relatively wider distribution with a clear peak at ~ 0.5 . The difference in distribution of dispersion confirms the separation of the 24 LGRBs into the two subgroups, although the origin of the difference is out of the scope of this paper.

3 DISCUSSION AND SUMMARY

The distributions of $\log E_{\gamma, \text{iso}}$ for both subgroups are shown in right-bottom panel in Figure 2. The symbols are the same as that in the right panel of Figure 1. Both subgroups have similar dynamical range of $\log E_{\gamma, \text{iso}}$, a sub-luminous LGRB (GRB 020903) is, however, only found in Group L. The Amati relation is also fitted through Eq. (1) after excluding the sub-luminous GRB 020903 from Group L. We obtain a relation with $a = -3.48 \pm 0.96$ and $b = 1.74 \pm 0.36$ ($\chi_r^2 = 1.33$), which confirms the consistence of our fitting.

The $L - Z$ relation has been firmly established in the local Universe ($z < 1$) base upon various spectroscopic surveys (e.g., Tremonti et al. 2004; Savaglio et al. 2005; Liang et al. 2006). The $L - Z$ relation indicates that, in general, high metallicity is found in luminous galaxies, and low metallicity in faint galaxies. Tremonti et al. (2004) obtained a relationship $12 + \log(\text{O}/\text{H}) = -0.185M_B + 5.238$ with a typical scatter of $\sigma_{12+\log(\text{O}/\text{H})} = 0.16$ from SDSS. The existent observations indicate that local LGRBs' host galaxies are not far from the $L - Z$ relation (e.g., Savaglio et al. 2006). The median value of absolute magnitude is $M_B = -20.35$ mag for Group H, and -18.55 mag for Group L. According to the relationship derived by Tremonti et al. (2004), the difference of metallicity is inferred to be 0.33 dex which is two times larger than the dispersion of the $L - Z$ relation. Recent observations revealed an evolution of the zero point of the $L - Z$ relation from local Universe to intermediate redshift $z = 1$. Different evolution are, however, found by various authors. For instance, Liang et al. (2006) found an evolution of 0.3 dex since $z = 0.65$, while a much more moderate evolution of 0.14 dex is reported by Kobulnicky & Kewley (2004). In current study, the cosmological evolution is not a key issue because a majority of LGRBs in *both* two sub-groups are uniformly distributed in a relatively narrow dynamical range of redshift (from $z = 0.5$ to $z = 1$, see Figure 1). According to these existent observations, the consistence of the Amati relations for different luminosity of host galaxy implies that the Amati relation has no strong evolution with metallicity of LGRB's environment.

In the generally accepted fireball model, the Amati relation could be explained by the standard internal shock scenario, $E_p \propto \Gamma^{-2} L^{1/2} t_{\text{var}}^{-1}$, where Γ is the fireball bulk Lorentz factor, L is the GRB luminosity and t_{var} is the typical variability time scale (e.g., Zhang & Mészáros 2002; Rees & Mészáros 2005; Ryde 2005). The agreement of the Amati relations in the two subgroups would consequently require that both Γ and t_{var} are approximately independent on environment metallicity. An alternative explanation of the Amati relation is the thermal radiation from photosphere of GRB (e.g., Rees & Mészáros 2005; Thompson 2006; Thompson et al. 2007). In such a context, one expects $E_p \propto R_0^{-1/2} \Delta t_j^{-1/4} E_{\gamma, \text{iso}}^{1/2}$, where R_0 is the radius of complete thermalization. Such radius is reasonably assumed to be comparable or less than the radius of core of the progenitor. Because of the weak dependence on the duration of prompt emission, the slope of the Amati relation primarily depends on the radius. Our test therefore implies a similar core radius of progenitor in both subgroups.

The result obtained in this paper differs from that in Li (2007). Li (2007) found the variation of the Amati relation by separating the whole sample into four groups according to redshift. However, various selection bias should be carefully considered in such study. In stead of the $E_p - E_{\gamma, \text{iso}}$ relation, a much lower dispersion is found in the $E_p - E_\gamma$ relation by correcting for collimation angles of jet (Ghirlanda et al. 2004; 2007). The different slope between the $E_p - E_{\gamma, \text{iso}}$ and $E_p - E_\gamma$ relation leads to a hypothesis that powerful bursts intrinsically have smaller opening angles (Ghirlanda et al. 2005). Assuming the $E_p - E_\gamma$ relation is intrinsic for all LGRBs, the dependence of opening angle on burst energy could be a possible explanation of the decrease of slope of the Amati relation with redshift, because sub-luminous bursts have been only detected in local Universe by now.

As done in Ghirlanda et al. (2005), assuming the $E_p - E_\gamma$ relation is intrinsic for all the LGRBs, it is possible to compare the properties of the burst environment in the two subgroups. So far, the uncertainties of burst environment have not been considered in the previous studies on the $E_p - E_\gamma$ relation. Moreover, the properties of the circumburst medium could provide some insight about the energy source of LGRB. The model of LGRB's afterglow lightcurves indicates that a homogeneous medium is more favored than a wind like r^{-2} radial stratification (e.g., Panaitescu 2005; and recently summarized in Fryer et al. 2007). The observed homogeneous medium could be explained by either termination shock of wind (Wijers 2001) or bubbles with uniform density produced in intense starburst region (Chevalier et al. 2004).

In the homogeneous case, the density is (Sari 1999)

$$n = \frac{E_{\gamma, \text{iso}, 52}}{\eta} \left(\frac{\theta_j}{0.161} \right)^8 \left(\frac{t_j}{1+z} \right)^{-3} \text{ cm}^{-3} \quad (2)$$

where θ_j is the opening angle of jet, η is the radiation efficiency which is usually assumed to be the same for all bursts, $\eta = 0.2$ (Frail et al. 2001) and t_j is the break time in units of day of the afterglow light curve. The estimated density is shown in Column (7) in Table 1 for the 11 LGRBs with firm estimates of jet break

Table 1 The sample of 24 LGRBs used in this work

GRB	z	$E_{\gamma, \text{iso}}$ (erg s^{-1})	E_p (keV)	M_B (mag)	t_j (day)	n (cm^{-3})	Ref
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
970228	0.695	1.86 ± 0.14	195 ± 64	-17.85	....	.....	1,2
970508	0.835	0.71 ± 0.15	145 ± 43	-17.85	....	.....	1,2
970828	0.98	34 ± 4	586 ± 117	-18.85	2.2	2.04	1,2,7
980613	1.096	0.68 ± 0.11	194 ± 89	-19.85	....	.....	1,2
980703	0.966	8.3 ± 0.8	503 ± 64	-20.90	3.4	4.18	1,2,7
990123	1.60	266 ± 43	1724 ± 466	-20.40	2.04	3.43	1,2,8
990506	1.30	109 ± 11	677 ± 156	-19.75	....	.....	1,2
990510	1.619	20 ± 3	423 ± 42	-17.20	1.6	2.50	1,2,7
990705	0.842	21 ± 3	459 ± 139	-21.65	1.0	1.01	1,2,7
990712	0.434	0.78 ± 0.15	93 ± 15	-19.35	1.6	1.21	1,2,7
991208	0.706	25.9 ± 2.1	313 ± 31	-18.30	....	.....	1,2
991216	1.02	78 ± 8	648 ± 134	-18.15	1.2	1.94	1,2,7
000210	0.846	17.3 ± 1.9	753 ± 26	-19.50	....	.....	1,2
000418	1.12	10.6 ± 2.0	284 ± 21	-19.90	....	.....	1,2
000911	1.06	78 ± 16	1856 ± 371	-18.80	....	.....	1,2
010921	0.45	1.10 ± 0.11	129 ± 26	-19.75	....	.....	1,2
011121	0.36	9.9 ± 2.2	793 ± 533	-16.15	....	.....	1,2
020405	0.69	12.8 ± 1.5	612 ± 122	-21.50	1.67	29.49	1,2,7
020813	1.25	76 ± 19	590 ± 151	-19.30	0.43	2.04	1,2,7
020903	0.25	0.0028 ± 0.0007	3.37 ± 1.79	-19.2	....	.....	1,3
030328	1.52	43.0 ± 4.0	328 ± 55	-20.4	0.8	0.58	1,4,7
030528	0.782	2.0 ± 0.7	57 ± 9	-21.4	....	.....	1,5
050223	0.5840	10 ± 4.6	109.6 ± 60.6	-20.0	....	.....	1,6
050416	0.65	0.12 ± 0.02	25.1 ± 4.2	-20.3	1.0	1.17	1,9

Note 1. References: 1. Amati 2006a; 2. Le Floch et al. 2003; 3. Hammer et al. 2006; 4. Gorosabel, J., et al. 2005; 5. Rau et al. 2005; 6. Pellizza et al. 2006; 7. Ghirlanda et al. 2007; 8. Ghirlanda et al. 2004; 9. Soderberg et al. 2007

time (as shown in Column 6 in Table 1). For all the 11 LGRBs, the inferred values of density are consistent with the observations. The measured density roughly extends from 1 to 10 cm^{-3} (e.g., Frail et al. 2001; Panaitescu & Kumar 2002; Schaefer et al. 2003). Comparing the density between Group H and Group L, it is noted that the distribution of density in Group L is roughly concentrated around the value of 2 cm^{-2} . On the contrary, the density spreads wider in Group H than in Group L.

We note here that our treatment of binning the sample into two subgroups according to B-band luminosity of host galaxies is more or less simplified. The B-band luminosity is not a perfect indicator of stellar mass (or metallicity) because it suffers from extinction and traces mass of only massive stars. More accurate treatment of binning and direct measurement of metallicity are required to accurately test the evolution of the Amati relation.

In summary, we examine the systematics of the Amati relation by dividing the 24 LGRBs into two subgroups according to the absolute B-band magnitudes of their host galaxies. Obvious difference of Amati relations in the two subgroups are not found within uncertainties, although they seem to have different distributions of deviation from the best fit. Combining with the well established luminosity - metallicity relation, current study does not imply strong evolution of the Amati relation with LGRB's environment metallicity.

Acknowledgements The authors would like to thank the anonymous referee for his/her suggestions and comments on the manuscript. We thank Zheng W. K., Prof. Wei J. Y and Hu J. Y. for discussions. This work was funded by the NSF of China (NSFC), under grant 10673014.

References

Amati L., 2003, ChJAS, 3, 455

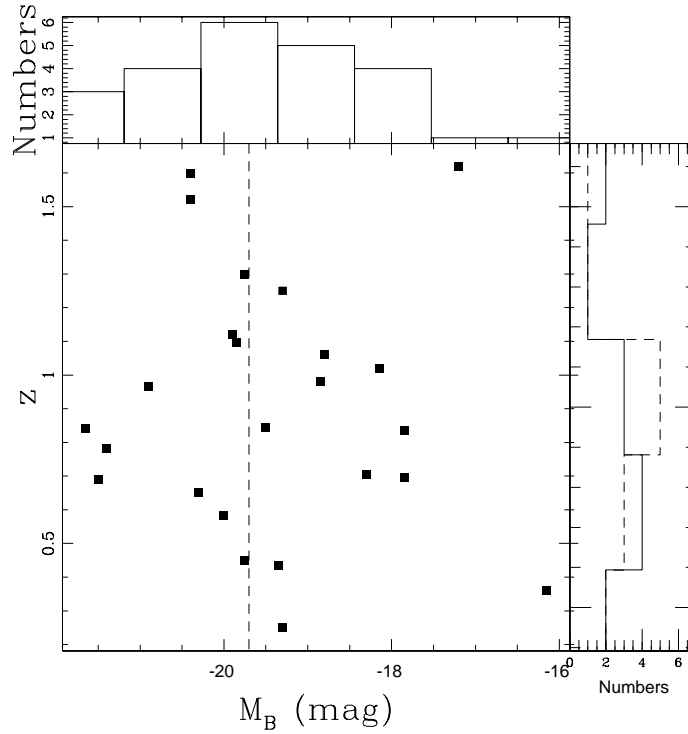


Fig. 1 *Bottom-left panel:* absolute B-band magnitude of LGRB's host galaxies plotted against redshift. The vertical dashed line marks the point $M_B = -19.7$ which is used to divide the 24 LGRBs into two subgroups (see text for details). *Upper panel:* the distribution of absolute B-band magnitude of LGRB's host galaxies. *Bottom-right panel:* distributions of redshift for the two subgroups (solid line for Group H, and dashed line for Group L).

- Amati L., 2006a, MNRAS, 372, 233
Amati L., 2006b, II Nuovo Cimento C, in press (arXiv: astro-ph/0611189v2)
Amati L., Frontera F., Tavani M., et al., 2002, A&A, 390, 81
Chevalier R., Li Z., Fransson C., 2004, ApJ, 606, 369
Frail D. A., Kulkarni S. R., Sari R., et al., 2001, ApJL, 562, 55
Fryer C. L., Mazzali P. A., Prochaska J., et al., 2007, arXiv: astro-ph/0702338
Fynbo J. P. U., Starling R. L. C., Ledoux C., et al., 2006, A&A, 451, L47
Ghirlanda G., Ghisellini G., Lazzati D., 2004, ApJ, 616, 331
Ghirlanda G., Ghisellini G., Firmani C., 2005, MNRAS, 361, L10
Ghirlanda G., Nava L., Ghisellini G., et al., 2007, A&A, 466, 127
Gorosabel J., Jelínek M., de Ugarte Postigo A., et al., 2005, NCimC, 28, 677
Hammer F., Flores H., Schaerer D., et al., 2006, A&A, 454, 103
Izotov Y. I., Papaderos P., Guseva N. G., et al., 2006, A&A, 454, 137
Kewley L. J., Brown W. R., Geller M. J., et al., 2007, AJ, 133, 882
Kobulnicky H. A., Kewley L. J., 2004, ApJ, 617, 240
Lamb D. Q., Donaghy T. Q., Graziani C., et al., 2004, NewAR, 48, 459

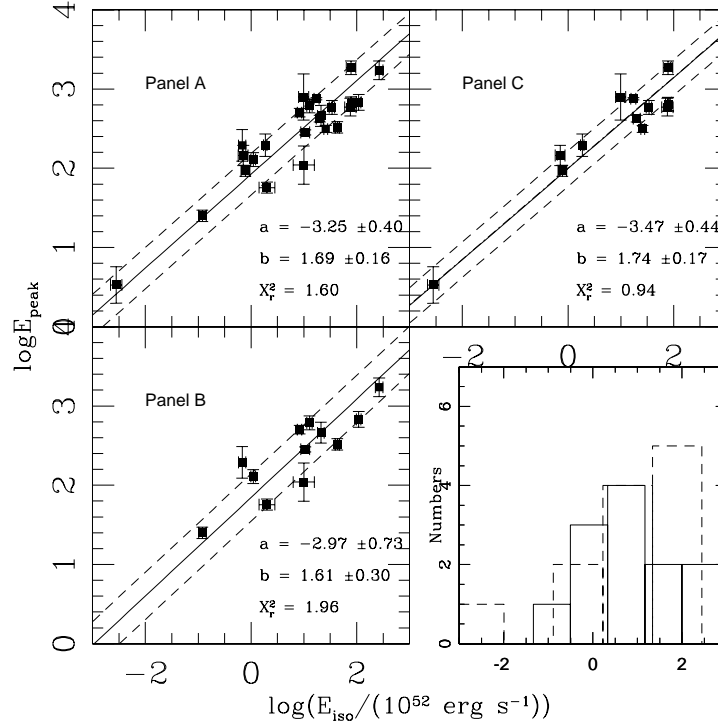


Fig. 2 Least squares fits (solid lines) to the 24 LGRBs as a single sample (*Panel A*), to Group H (*Panel B*) and Group L (*Panel C*). The two dashed lines in each panel mark the 1σ deviation from the best fit. *Right-bottom Panel*: Distributions of $\log E_{\gamma, \text{iso}}$ for Group H and L. The symbols are the same as that in Figure 1.

- Le Floc'h E., Duc P.-A., Mirabel I. F., et al. 2003, A&A, 400, 499
 Li L. X., 2007, MNRAS, 379, L55
 Liang E. W., Dai Z. G., Wu X. F., 2004, ApJL, 606, 29
 Liang Y. C., Hammer F., Flores, H., 2006, A&A, 447, 113
 MacFadyen A. I., Woosley S. E., 1999, ApJ, 524, 262
 Panaitescu A., 2005, MNRAS, 363, 1409
 Panaitescu A., Kumar P., 2001, ApJ, 554, 667
 Pellizza L. J., Duc P. -A., Le Floc'h E., et al., 2006, A&A, 459, 5
 Rau A., Salvato M., Greiner J., 2005, A&A, 444, 425
 Rees M., & Mészáros P., 2005, ApJ, 628, 847
 Ryde F., 2005, ApJL, 625, 95
 Sakamoto T., Lamb D. Q., Graziani C., et al., 2004, ApJ, 602, 875
 Sari R., 1999, ApJL, 524, 43
 Savaglio S., Glazebrook K., Le Borgne D., et al., 2005, ApJ, 535, 260
 Savaglio S., Glazebrook K., Le Borgne D., 2006, in Gamma-Ray Bursts in the Swift Era, AIP Conf. Proc., Vol. 838.,
 ed. S. S. Holt, N. Gehrels, & J. A. Nousek (Melville: American Inst. of Phys.), 540 (arXiv: astro-ph/0601528)
 Schaefer B. E., 2003, ApJL, 583, 67

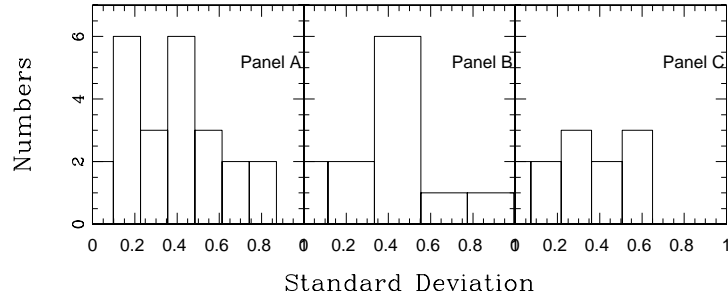


Fig. 3 *Panel A*: Distribution of deviation from the best fit for the whole sample. *Panel B* and *C*: The same but for Group H and L, respectively.

- Schaefer B. E., 2007, ApJ, 660, 16
 Soderberg A. M., Nakar E., Cenko S. B., et al., 2007, ApJ, 661, 982
 Sollerman J., Östlin G., Fynbo J. P. U., et al., 2005, NewA, 11, 103
 Stanek K. Z., Gnedin O. Y., Beacom J. F., et al., 2006, AcA, 56, 333
 Thompson C., 2006, ApJ, 651, 333
 Thompson C., Mészáros P., Rees M., 2007, ApJ, 666, 1012
 Tremonti C. A., Heckman T. M., Kauffmann G., et al., 2004, ApJ, 613, 898
 Wijers R., 2001, “Gamma-Ray Burst in the Afterglow Era”, eds, E. Costa, F. Frontera, J. Jorth (Berlin: Springer-Verlag), 306
 Woosley S. E., 1993, ApJ, 405, 273
 Woosley S. E., Bloom J. S., 2006, ARA&A, 44, 507
 Zhang B., & Mészáros P., 2002, ApJ, 581, 1236